10/517624

© EPODOC / EPO

DT12 Rec'd PCT/PTO 06 DEC 2004

PN - JP2002232032 A 20020816

PD - 2002-08-16

PR - JP20010025160 20010201

OPD - 2001-02-01

IC - H01L41/22

TI - Multilayer piezoelectric transducer polarization for mobile telephone, involves performing primary and secondary polarizations, such that degree of remanence after secondary polarization in piezoelectric layer, is less

PR - JP20010025160 20010201

PN - JP2002232032 A 20020816 DW200270 H01L41/22 011pp

PA - (MURA) MURATA MFG CO LTD

IC - H01L41/22

AB - JP2002232032 NOVELTY - A unidirectional electric field is impressed along width direction of a transducer, so that primary polarization takes place uniformly. The electric field in the opposite direction is applied to the piezoelectric layers (1b,1c) on both sides of an inner electrode, so that a polarization axis on one side of the layer (1b) is reversed. A secondary polarization is performed, such that degree of remanence after the secondary polarization is less.

- USE - For polarizing multilayer peizoelectric transducer used in mobile telephone.

- ADVANTAGE - Polarization of the transducer is performed uniformly. Field is improved. Favorable resonance characteristics is obtained.

- DESCRIPTION OF DRAWING(S) - The figure shows the polarization distribution of the piezoelectric transducer. (Drawing includes non-English language text).

- Piezoelectric layers 1b,1c

- (Dwg.4/13)

OPD - 2001-02-01

AN - 2002-650453 [70]

(19)日本国特許庁（ＪＰ）　(12) 公開特許公報（Ａ）　(11)特許出願公開番号
特開2002－232032
（P2002－232032A）
(43)公開日　平成14年8月16日(2002.8.16)

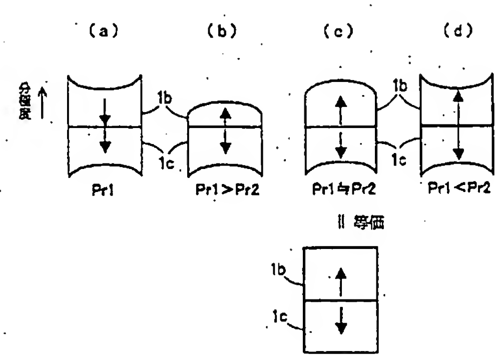
(51)Int.Cl.^{7}	識別記号	ＦＩ	テーマコード゛(参考)
Ｈ０１Ｌ　41/22		Ｈ０１Ｌ　41/22	Ｂ
			Ｚ

審査請求　未請求　請求項の数４　ＯＬ　（全 11 頁）

(21)出願番号　特願2001－25160(P2001－25160)
(22)出願日　平成13年2月1日(2001.2.1)
(71)出願人　000006231
株式会社村田製作所
京都府長岡京市天神二丁目26番10号
(72)発明者　中島　幹雄
京都府長岡京市天神２丁目26番10号　株式会社村田製作所内
(74)代理人　100085497
弁理士　筒井　秀隆

(54)【発明の名称】　積層圧電体の分極方法

(57)【要約】
【課題】積層圧電体の分極度分布を均一にし、収率の向上を図る積層圧電体の分極方法を提供する。
【解決手段】複数の圧電体層１ａ～１ｄと複数の内部電極２ａ～２ｃとを交互に積層し、隣合う圧電体層１ｂ，１ｃを厚み方向に互いに逆方向に分極する積層圧電体１の分極方法において、積層圧電体１に対し厚み方向に一方向の電界を印加し、厚み方向に一様に分極する一次分極工程と、内部電極２ｂの両側の圧電体層１ｂ，１ｃに逆向きの電界を印加し、内部電極２ｂの片側の圧電体層１ｂの分極軸のみを反転させる二次分極工程とを備える。二次分極は、分極軸が反転した圧電体層１ｂにおける二次分極後の残留分極度Ｐｒ$_2$ が一次分極後の残留分極度Ｐｒ$_1$ を越えない範囲で行われる。



【特許請求の範囲】
【請求項１】複数の圧電体層と複数の内部電極とを交互に積層し、隣合う圧電体層を厚み方向に互いに逆方向に分極する積層圧電体の分極方法において、上記積層圧電体に対し厚み方向に一方向の電界を印加し、厚み方向に一様に分極する一次分極工程と、上記内部電極の両側の圧電体層に互いに逆向きの電界を印加し、内部電極の片側の圧電体層の分極軸のみを反転させる二次分極工程とを備え、上記二次分極は、分極軸が反転した圧電体層における二次分極後の残留分極度Pr_2が一次分極後の残留分極度Pr_1を越えない範囲で行われることを特徴とする積層圧電体の分極方法。
【請求項２】上記一次分極工程は、上記積層圧電体の厚み方向に第１の方向の電界を印加する第１の工程と、上記積層圧電体の厚み方向に第１の方向と逆方向の電界を印加する第２の工程とを含み、上記第２の工程によって第１の工程で形成された積層圧電体の分極軸を一様に反転させることを特徴とする請求項１に記載の積層圧電体の分極方法。
【請求項３】複数の圧電体層と複数の内部電極とを交互に積層し、隣合う圧電体層を厚み方向に互いに逆方向に分極する積層圧電体の分極方法において、上記内部電極の両側の圧電体層に互いに逆向きの電界を印加し、内部電極の両側の圧電体層を互いに逆向きに分極する一次分極工程と、上記内部電極の両側の圧電体層に、一次分極工程における電界と反対方向の電界を互いに逆向きに印加し、内部電極の両側の圧電体層の分極軸を反転させる二次分極工程とを備え、上記二次分極は、分極軸が反転した圧電体層における二次分極後の残留分極度Pr_2が一次分極後の残留分極度Pr_1を越えない範囲で行われることを特徴とする積層圧電体の分極方法。
【請求項４】上記一次分極はブロック状の積層圧電体に対して行なわれ、二次分極はブロック状の積層圧電体を内部電極に対して垂直な方向に１素子分の幅で切断してなる短冊状の積層圧電体に対して行われることを特徴とする請求項１ないし３のいずれかに記載の積層圧電体の分極方法。
【発明の詳細な説明】
【０００１】
【発明の属する技術分野】本発明は、例えば携帯電話のフィルタなどに使用される積層圧電体の分極方法、特に複数の圧電体層と複数の内部電極とを交互に積層し、隣合う圧電体層を厚み方向に互いに逆方向に分極する積層圧電体の分極方法に関するものである。
【０００２】
【従来の技術】従来、特性の設計自由度が大きく、スプリアスが小さく、共振周波数と反共振周波数との差ｄｆを大きくできる長さモード圧電共振子が提供されている（特開平１０－４３３０号公報）。図１はこの長さモード圧電共振子１０の一例を示す。圧電共振子１０は、複数の圧電体層１２と複数の内部電極１３とが交互に積層された基体１１を持ち、内部電極１３の両側の圧電体層１２が互いに逆向きに分極されている。基体１１の対向面には、１つおきに内部電極１３を被覆する絶縁膜１４，１５が形成され、さらにその上に外部電極１６，１７が形成されている。そのため、外部電極１６，１７は内部電極１３に対して１つおきに交互に接続される。このような構造の圧電共振子１０の場合、圧電体層１２の分極度が特性に大きく影響するので、各素子内での分極度バラツキおよび素子間での分極度バラツキをできるだけ小さくすることが求められる。
【０００３】この種の圧電共振子は、ブロック状の積層圧電体を形成し、これを分極した後、細分することで製作する。積層圧電体の分極処理は、図２に示す方法で行なっている。１はブロック状の圧電セラミックスよりなる積層圧電体であり、ここでは説明を簡単にするため４層の圧電体層１ａ～１ｄで構成されたものを示すが、実際には多層に積層されたものである。圧電体層１ａ～１ｄの間には内部電極２ａ～２ｃが設けられ、内部電極２ａ～２ｃは圧電体１の外側面に交互に引き出され、側面電極３，４と接続されている。そして、側面電極３，４間に直流電界を印加することにより、内部電極２ｂの両側の圧電体層１ｂ，１ｃを矢印Ｐで示すように互いに逆向きに分極し、所定の分極度を得ている。
【０００４】ところが、図２のような方法では、内部電極２ａ～２ｃの端部に電界が集中するため、分極度分布が均一にならないという問題があった。図３は１つの圧電体層における分極度分布の一例を示し、斜線は分極度を表す。図から分かるように、圧電体１に対し厚み方向に電界を印加すると、圧電体１の四隅部の分極度が著しく高くなり（凹状分布）、均一な分極度分布が得られない。その結果、このような分極度分布が不均一な圧電体層を積層したもの（ブロック）を短冊状に切り出し、さらに短冊をカットして素子として使用する場合、ブロックの周辺部の圧電体は使用できなくなり、圧電体の使用範囲（収率）が大きく制限されてしまうという問題があった。
【０００５】例えばラダー型フィルタに用いられる直列共振子（ｆｒ＝４５０ｋＨｚ，ｄｆ＝５５ｋＨｚ）用の積層圧電体を図２のような方法で分極すると、ブロック内の分極度ｄｆのばらつきは約１０ｋＨｚにも及ぶ大きな分布を示す。そのため、良品として使用できる素子はブロック中央付近から切り出された素子のみで、ブロック周辺の素子は殆ど分極不良となっていた。
【０００６】そこで、本願出願人は、積層圧電体の対向する主面の外部電極に電界を印加して、積層圧電体の厚み方向に一方向の分極（初期分極）を行った後、内部電極を交互に外部に引き出す側面電極を形成し、側面電極間に電界を印加して内部電極の片側の圧電体層の分極軸のみを反転させ（分極反転）、所望の分極度を得る方法

を提案した（特願2000－52743号）。この方法は、図4に示すように、初期分極の段階では周辺部と中央部とでΔP_1の分極度ばらつきがある場合でも、逆方向の電界をかけて分極軸を反転させると、ΔP_2まで分極度ばらつきを小さくでき、初期分極時の分極度分布の不均一が是正されるという知見に基づいている。

【0007】

【発明が解決しようとする課題】しかしながら、分極軸が反転した圧電体層の飽和分極度Pmax を、初期分極時の飽和分極度Pmax とほぼ等しくなるまで分極すると、分極度ばらつきが小さくなったとは言え、分極反転させた圧電体層の分極度分布は反転前と同様に凹状になってしまう。そのため、上記の方法で分極軸が逆向きの圧電体層が交互に積層された積層圧電体を構成した場合、凹状分布を持つ分極反転した圧電体層と凹状分布を持つ分極反転しない圧電体層とが交互に積層されることになり、積層圧電体全体としてみると、必ずしも均一な分極度分布が得られない可能性があった。

【0008】そこで、本発明の目的は、積層圧電体全体の分極度分布をできるだけ均一にし、収率の向上を図る積層圧電体の分極方法を提供することにある。

【0009】

【課題を解決するための手段】上記目的は、請求項1または3に記載の発明により達成される。すなわち、請求項1に記載の発明は、複数の圧電体層と複数の内部電極とを交互に積層し、隣合う圧電体層を厚み方向に互いに逆方向に分極する積層圧電体の分極方法において、上記積層圧電体に対し厚み方向に一方向の電界を印加し、厚み方向に一様に分極する一次分極工程と、上記内部電極の両側の圧電体層に互いに逆向きの電界を印加し、内部電極の片側の圧電体層の分極軸のみを反転させる二次分極工程とを備え、上記二次分極は、分極軸が反転した圧電体層における二次分極後の残留分極度Pr_2が一次分極後の残留分極度Pr_1を越えない範囲で行われることを特徴とする積層圧電体の分極方法を提供する。また、請求項3に記載の発明は、複数の圧電体層と複数の内部電極とを交互に積層し、隣合う圧電体層を厚み方向に互いに逆方向に分極する積層圧電体の分極方法において、上記内部電極の両側の圧電体層に互いに逆向きの電界を印加し、内部電極の両側の圧電体層を互いに逆向きに分極する一次分極工程と、上記内部電極の両側の圧電体層に、一次分極工程における電界と反対方向の電界を互いに逆向きに印加し、内部電極の両側の圧電体層の分極軸を反転させる二次分極工程とを備え、上記二次分極は、分極軸が反転した圧電体層における二次分極後の残留分極度Pr_2が一次分極後の残留分極度Pr_1を越えない範囲で行われることを特徴とする積層圧電体の分極方法を提供する。

【0010】請求項1では、積層圧電体に対し厚み方向に一方向の電界を印加し、厚み方向に一様に分極する一次分極を行う。次に、内部電極の両側の圧電体層に逆向きの電界を印加し、内部電極の片側の圧電体層の分極軸のみを反転させる二次分極を行う。図5は請求項1にかかる分極方法の一例を示す。まず、積層圧電体1の表裏面に表裏電極5，6を形成し、積層圧電体1に対し厚み方向の直流電界を印加して厚み方向に一方向に分極（一次分極）する。その後、内部電極2a～2cを積層圧電体1の外側面に交互に引き出し、側面電極3，4と接続する。そして、側面電極3，4間に直流電界を印加することにより、内部電極2bの両側の圧電体層1b，1cに互いに逆向きの電界を印加し、内部電極2bの片側の圧電体層1bの分極軸のみを反転させる（二次分極）。なお、内部電極2bの他側の圧電体層1cは再分極されるだけで、分極軸は反転しない。

【0011】本発明者は、二次分極時の分極条件を変えて種々実験を行ったところ、二次分極の進行度（残留分極度）によって、分極軸が反転した圧電体層1bの分極度分布が変化することを発見した。図6は二次分極の進行に伴う2つの圧電体層1b，1cにおける分極度分布の変化の一例をモデル化して示したものである。矢印は分極方向を示す。（a）は一次分極後の分極度分布であり、共に凹状分布を有する。（b）～（d）は二次分極の進行に伴う分極度分布の変化を示す。なお、Pr_1は一次分極による残留分極度、Pr_2は二次分極による残留分極度を示す。図6から明らかなように、圧電体層1bの分極度分布は、分極軸が反転した当初は（b），（c）のように凸状あるいはフラットな分布を示すが、やがて（d）のように凹状に変化する。なお、図6では（b），（c）における圧電体層1bの分極度分布が凸状の例を示すが、材料によってはほぼフラットな分布を示すものもある。このように二次分極が進み過ぎると、圧電体層1bの分極度分布は一次分極時と同様な凹状の分布（ただし分極方向は逆）になってしまう。なお、再分極された圧電体層1cの分極度分布は依然として凹状のままである。したがって、（d）のように逆分極が進み過ぎた状態では、分極反転した圧電体層1bの分極度分布と分極反転しない圧電体層1cの分極度分布とが共に凹状となり、圧電体全体としてみると均一な分極度分布にならない。

【0012】そこで、請求項1では、分極軸が反転した圧電体層1bの分極度分布が凸状あるいはフラットとなる範囲で二次分極を停止するものである。つまり、二次分極後の残留分極度Pr_2が一次分極後の残留分極度Pr_1を越えない範囲で二次分極している。

$Pr_1 \geqq Pr_2$

このようにすれば、分極軸が反転した圧電体層1bの分極度分布が凸状あるいはフラットで、分極軸が反転しない圧電体層1cの分極度分布が凹状であるから、両層の総和として凸状の分極度分布と凹状の分極度分布とが相殺し合うか、あるいは凹状分布の不均一度が相対的に低

減され、積層圧電体１全体としてみると、ほぼ均一な分極度分布が得られる。その結果、圧電体の使用範囲が拡がり、収率が向上する。なお、$Pr_1 > Pr_2$ の場合には、２つの層１ｂ，１ｃの分極度の大きさがアンバランスになるが、分極度分布がほぼ均一であれば、長さ振動モード素子としての共振特性には悪影響がない。特に、$Pr_2 \fallingdotseq Pr_1$ とすれば、図６の（ｃ）のように２つの層１ｂ，１ｃの分極度の大きさがほぼ等しく、均一な分布の積層圧電体と等価になり、最も良好な特性となる。

【００１３】請求項２では、一次分極工程が、積層圧電体の厚み方向に第１の方向の電界を印加する第１の工程と、積層圧電体の厚み方向に第１の方向と逆方向の電界を印加する第２の工程とを含み、第２の工程によって第１の工程で形成された積層圧電体の分極軸を一様に反転させることを特徴としている。すなわち、一次分極、つまり積層圧電体に対し厚み方向に一様に分極する工程を１回だけ実施してもよいが、図４の初期分極と同様に、分極度分布が凹状になり、中央部と端部との差ΔP_1 が大きい。そこで、一次分極を複数回実施し、積層圧電体全体にわたって分極軸を反転させれば、図４の分極反転と同様に、中央部と端部との差ΔP_2 が小さくなり、分極度分布の不均一を是正することができる。このように一次分極における分極度分布の不均一を是正することで、二次分極後の圧電体層の分極度分布の不均一も是正される。なお、第２の工程の回数は１回に限らず、複数回実施してもよい。

【００１４】請求項３では、まず内部電極の両側の圧電体層に互いに逆向きの電界を印加し、内部電極の両側の圧電体層を互いに逆向きに分極する一次分極を行う。一次分極の後、内部電極の両側の圧電体層に、上記電界と反対方向の電界を互いに逆向きに印加し、内部電極の両側の圧電体層の分極軸を反転させる二次分極を行う。つまり、内部電極の両側の圧電体層が最初の分極軸方向と反転する。図７は請求項３にかかる分極方法の一例を示す。まず、内部電極２ａ～２ｃを積層圧電体１の外側面に交互に引き出し、これら内部電極２ａ～２ｃと導通する側面電極３，４を形成する。そして、側面電極３，４間に直流電界を印加することにより、内部電極２ｂの両側の圧電体層１ｂ，１ｃを互いに逆向きに分極する（一次分極）。この分極工程は、従来（図２参照）における分極工程と同じである。次に、側面電極３，４間に逆方向の直流電界を印加し、内部電極２ｂの両側の圧電体層１ｂ，１ｃの分極軸を同時に反転させる（二次分極）。この場合も、分極軸が反転した圧電体層１ｂ，１ｃにおける二次分極後の残留分極度Pr_2 が一次分極後の残留分極度Pr_1 を越えない範囲で、二次分極を行う。この場合には、内部電極２ｂの両側の圧電体層１ｂ，１ｃの分極軸が反転し、再分極層が存在しないので、２つの層１ｂ，１ｃの分極条件が同じになり、分極度分布の均一化を図るとともに、２つの層１ｂ，１ｃの分極度の大きさを同じにできる。

【００１５】図８は図７に示す方法で２次分極を行った場合の圧電体層１ｂ，１ｃにおける分極度分布の変化を示す。矢印は分極方向を示す。（ａ）は一次分極後の分極度分布であり、共に凹状分布を有する。（ｂ）～（ｄ）は二次分極の進行に伴う分極度分布の変化を示す。二次分極によって分極軸が反転した後、２つの層１ｂ，１ｃの分極度がほぼ等しく、その分極度分布が共にフラットあるいはやや凸状の分布となり、両層１ｂ，１ｃの分極度分布の不均一度が低減される。そして、残留分極度Pr_2 を一次分極による残留分極度Pr_1とほぼ一致するまで二次分極を行うと、（ｃ）のように２つの層１ｂ，１ｃが共にフラットあるいはやや凸状の分布で、かつ分極度も高くなり、理想的な分布となる。二次分極がさらに進行すると、（ｄ）のように凹状の分布となる。したがって、$Pr_1 \geqq Pr_2$ となるように二次分極条件を設定することで、全体として均一な分極度分布を持つ積層圧電体１を得ることができる。

【００１６】請求項４のように、一次分極工程をブロック状の積層圧電体に対して行ない、二次分極工程を短冊状の積層圧電体に対して行うのが望ましい。すなわち、生産性を高めるためには、一次分極および二次分極を共にブロック状の積層圧電体に対して行なうのがよいが、一次分極時における分極度分布の不均一は図３に示すように３次元的に現れるので、ブロック状態のまま二次分極を行うと、分極度分布の不均一を解消しにくい。そこで、短冊状に切り出した後で二次分極を行なえば、各短冊の分極度分布に応じて電界強度や時間を設定できるので、短冊間および短冊内の分極度バラツキを小さくすることが可能となる。

【００１７】請求項１の場合には、一次分極を行った積層圧電体は、厚み方向に一様に分極されているので、長さ振動が励振されない。そこで、拡がり振動モードの共振周波数と反共振周波数との差ＤＦを求め、これを分極度としている。一方、二次分極を行った積層圧電体は分極方向が相反する層を有するので、長さ振動が励振され、この長さ振動モードの共振周波数と反共振周波数との差ｄｆを求めて分極度としている。このように振動モードの異なる２種類の分極度をそのまま比較できないので、一次分極後の積層圧電体の拡がり振動のＤＦを電気機械結合係数Ｋに換算して残留分極度Pr_1 とし、二次分極後の積層圧電体の長さ振動のｄｆを電気機械結合係数Ｋに換算して残留分極度Pr_2 とし、この残留分極度Pr_1 ，Pr_2 を比較することで、二次分極の範囲を決定している。また、請求項３の場合には、一次分極を行った積層圧電体の段階で、分極方向が相反する層を有するので、長さ振動が励振される。そのため、一次分極の残留分極度Pr_1 も二次分極の残留分極度Pr_2 も共に、長さ振動の共振周波数と反共振周波数との差ｄｆを電気機械結合係数Ｋに換算した値から求めることができ

る。

【0018】

【発明の実施の形態】図9は所定のＰＺＴ系圧電セラミックスについて、一次分極の残留分極度Pr_1＝５０ｋＨｚとした場合に、二次分極の印加電圧を変化させた時の短冊での分極軸が反転する層（分極反転層と呼ぶ）の分極度Pr_2の変化を示し、図１０は図９のＡ～Ｆの各点における分極度分布を示している。なお、参考までに、図９には印加電圧を変化させた時の圧電体層（正分極層と呼ぶ）の分極度の変化も図示してある。圧電体層の厚みは０．５６ｍｍとした。

【００１９】図９，図１０から明らかなように、分極反転層では二次分極の電圧上昇に伴って減極し、約９００ｖで分極軸が反転し、それ以後は分極度が上昇する。分極反転後、二次分極の電圧が約１０００ｖ付近になると、分極反転層の残留分極度Pr_2が約５０ｋＨｚとなり、一次分極の残留分極度Pr_1とほぼ等しくなる。二次分極の電圧が９００ｖ～約１０００ｖ付近になるまでの間（Ｄ点，Ｅ点参照）、分極度分布がほぼフラットあるいはやや凸状であり、約１０００ｖ付近以上になると（Ｆ点参照）、分極度分布が凹状になることがわかる。よって、この場合の二次分極の電圧は、$Pr_1 \geq Pr_2$の範囲、つまり９００ｖ～１０００ｖの範囲とすればよい。

【００２０】なお、正分極層では５００ｖを越えるまでは分極度が０のままであるが、それ以後、分極度が上昇する。その間、短冊内での分極度分布は凹状のままで変化しない。図９，図１０には、再分極を行った圧電体層については図示していないが、再分極層の場合には、二次分極における電界が一次分極における分極度を越えるまで変化せず、一次分極の分極度を越えて初めて、二次分極における分極度が優勢となる。その間、正分極層と同様に短冊内での分極度分布は凹状のままで変化しない。

【００２１】以下に、本発明に係る積層圧電体の分極方法の実施例と比較例とを説明する。本実施例では、長さモード圧電共振子（ｄｆ＝５５ｋＨｚ）の材料としてＰＺＴ系の積層圧電体を用いた。

【００２２】〔第１実施例〕図１１は第１実施例の長さモード圧電共振子の製造工程を示す。まず、圧電セラミックスよりなるグリーンシートの片面に銀，パラジウム，有機バインダなどを含む内部電極用の導電ペーストを塗布し、これを交互に積層し、約１２００℃で一体的に焼成して２０ｍｍ×３０ｍｍ×３．９ｍｍのブロック状の積層圧電体１を形成した。そして、このブロック１の表裏面に表裏電極５，６を形成し、恒温槽において表裏電極５，６間に直流電界を印加し、一次分極を行った（図１１の（ａ）参照）。一次分極の条件は、電界：１．５ｋｖ／ｍｍ、分極時間：１０ｍｉｎ、保持温度：７０℃で一定とした。その後、１５０℃×１ｈｒの条件でエージング処理を行った。

【００２３】次に、一次分極後のブロック状積層圧電体１の側面に、内部電極を交互に引き出すための側面電極３，４を形成した。そして、この積層圧電体１をダイサーを用いて、内部電極２ａ～２ｃに対して垂直な方向に１素子分の幅で短冊状に切り出した。切り出された短冊１Ａに対し、側面電極３，４により直流電界を印加し、二次分極を行った（図１１の（ｂ）参照）。この時、個々の短冊１Ａの分極度を分極時間の制御により所定値に揃えた。二次分極の条件は、電界：１．５ｋｖ／ｍｍ、分極温度：７０℃で一定とした。分極時間を制御して、所定の分極度（長さモード素子の分極度ｄｆ＝５５ｋＨｚに対応した短冊の分極度）に調整した。その後、２５０℃×１ｈｒの条件でエージング処理を行った。

【００２４】二次分極の範囲は、二次分極後の短冊１Ａの長さ振動モードの共振周波数と反共振周波数との差ｄｆを電気機械結合係数Ｋに換算した値（残留分極度Pr_2）が、一次分極後のブロック１の拡がり振動モードの共振周波数と反共振周波数との差ＤＦを電気機械結合係数Ｋに換算した値（残留分極度Pr_1）を越えない範囲としている。すなわち、

$Pr_1 \geq Pr_2$

二次分極後の短冊１Ａに対し、側面に露出した電極を１つおきに絶縁材で被覆し、その上に銀電極を形成した。これをダイサーで切断して、１．５ｍｍ×１．５ｍｍ×３．８ｍｍの長さモード圧電共振子１Ｂを得た（図１１の（ｃ）参照）。この圧電共振子１Ｂの具体的構造は、図１と同様であるから、ここでは説明を省略する。

【００２５】〔比較例〕第１実施例と同様な方法でブロック状の積層圧電体を形成し、その側面に内部電極を交互に引き出すための側面電極を形成し、恒温槽において積層圧電体の側面電極に直流電界を印加し、分極を行った（図２参照）。分極条件は、電界：１．５ｋｖ／ｍｍ、保持温度：７０℃で一定とした。分極時間を制御して、所定の分極度ＤＦ＝２．０±０．２ｋＨｚに調整した。この場合の分極度ＤＦは、ブロックの拡がり振動モードの共振周波数と反共振周波数との差から求めた。その後、２５０℃×１ｈｒの条件でエージング処理を行い、所定寸法にカットして長さモード圧電共振子を得た。

【００２６】上記のようにして得られた２種類の素子のインピーダンスの周波数特性を測定し、共振周波数と反共振周波数との差として、ｄｆ＝５５ｋＨｚの値を得た。表１，表２は、特性分類工程での第１実施例と比較例の分極度ｄｆおよび共振周波数ｆｒのロット変動における比較を示す。σ_{n-1}は標準偏差、ｒは最大値と最小値との差である。

【００２７】

【表１】

ー第１実施例ー

評価工法（3ロット）

		評価ロット①	評価ロット②	評価ロット③	平均値
df	ave	56.15	55.82	55.03	55.67
	σ_{n-1}	0.90	0.92	0.90	0.91
	max	58.5	58.5	58.5	58.60
	min	54	53.5	52.5	53.33
	r	4.5	5	6	5.17

単位：KHz

		評価ロット①	評価ロット②	評価ロット③	平均値
fr	ave	450.8	449.72	449.86	450.13
	σ_{n-1}	0.90	1.03	1.10	1.01
	max	454	454	454.5	454.17
	min	448	447	447	447.33
	r	6	7	7.5	6.83

単位：KHz

【００２８】

【表２】

ー比較例ー

評価工法（5ロット）

		ロット①	ロット②	ロット③	ロット④	ロット⑤	平均値
df	ave	56.44	56.22	56.41	56.69	56.31	56.41
	σ_{n-1}	2.16	1.97	2.09	2.01	1.97	2.04
	max	63.00	62.50	62.50	63.00	63.00	62.80
	min	52.50	51.50	52.50	53.00	53.00	52.50
	r	10.50	11.00	10.00	10.00	10.00	10.30

単位：KHz

		ロット①	ロット②	ロット③	ロット④	ロット⑤	平均値
fr	ave	448.99	448.69	448.63	448.96	447.88	448.63
	σ_{n-1}	1.37	1.41	1.19	1.29	1.15	1.28
	max	452.50	452.00	451.50	452.00	450.50	451.70
	min	444.50	443.50	444.50	445.00	444.50	444.40
	r	8.00	8.50	7.00	7.00	6.00	7.30

単位：KHz

【００２９】表１，表２から明らかなように、ｄｆの標準偏差σ_{n-1}の平均値で比較すると、第１実施例では０．９１ｋＨｚ、比較例では２．０４ｋＨｚであり、第１実施例は比較例に比べて、分極度ｄｆのばらつきを約１／２に改善できた。また、共振周波数ｆｒの標準偏差σ_{n-1}の平均値で比較すると、第１実施例では１．０１ｋＨｚ、比較例では１．２８ｋＨｚであり、共振周波数ｆｒで約３０％のばらつきを改善できた。

【００３０】〔第２実施例〕図１２は第２実施例の長さモード圧電共振子の製造工程を示す。この実施例では、ブロック１の段階で一次分極を複数回実施し（図１２の（ａ）および（ｂ）参照）、ブロック１全体に亘って分極軸を反転させたものである。この場合には、図４の分極反転と同様に、中央部と端部との差ΔP_2が小さくなるので、（ｃ）で短冊１Ａにカットした段階で、短冊１Ａ間および短冊１Ａ内での分極度ばらつき（凹状分布）が小さくなる。そのため、（ｃ）で二次分極を行うと、二次分極後の再分極された圧電体層１ｃの凹状の分極度分布が均一化される。なお、（ｂ）の工程の回数は１回に限らず、複数回実施してもよい。

【００３１】表３は、第２実施例における分極度ｄｆおよび共振周波数ｆｒのロット変動を示す。表３から明らかなように、分極度ｄｆの標準偏差σ_{n-1}の平均値は０．８５ｋＨｚ、共振周波数ｆｒの標準偏差σ_{n-1}の平均値は０．９６ｋＨｚであり、第１実施例に比べてさらにばらつきを改善できた。

【００３２】

【表３】

－ｵ2実施例－

評価工法（3ロット）

		評価ロット①	評価ロット②	評価ロット③	平均値
df	ave	53.93	53.44	54.03	53.80
	σ_{n-1}	0.96	0.71	0.87	0.85
	max	58.00	55.00	57.50	56.83
	min	50.00	51.50	52.00	51.17
	r	8.00	3.50	5.50	5.67

単位：KHz

		評価ロット①	評価ロット②	評価ロット③	平均値
fr	ave	449.15	448.93	449.06	449.05
	σ_{n-1}	0.85	0.97	1.06	0.96
	max	451.50	452.00	451.50	451.67
	min	446.00	446.00	446.50	446.17
	r	5.50	6.00	5.00	5.50

単位：KHz

【００３３】〔第３実施例〕図１３は第３実施例の長さモード圧電共振子の製造工程を示す。圧電セラミックスよりなるグリーンシートの片面に銀，パラジウム；有機バインダなどを含む内部電極用の導電ペーストを塗布し、これを交互に積層し、約１２００℃で一体的に焼成して２０mm×３０mm×３．９mmのブロック状の積層圧電体１を形成した。そして、積層圧電体１の側面に内部電極を交互に引き出すための側面電極３，４を形成し、恒温槽において側面電極間に直流電界を印加し、一次分極を行った（図１３の（ａ）参照）。一次分極の条件は、電界：１．５ｋｖ／mm、分極時間：１０ｍｉｎ、保持温度：７０℃で一定とした。その後、１５０℃×１ｈｒの条件でエージング処理を行った。

【００３４】次に、エージング後のブロック状積層圧電体１をダイサーを用いて、内部電極に対して垂直な方向に１素子分の幅で短冊状に切り出した。切り出された短冊１Ａに対し、側面電極３，４により直流電界を印加し、二次分極を行った（図１３の（ｂ）参照）。この時、短冊１Ａへの電圧印加の方向は、一次分極と逆方向に行った。個々の短冊１Ａの分極度を分極時間の制御により所定値に一定に揃えた。二次分極の条件は、電界：１．５ｋｖ／mm、分極温度：７０℃で一定とした。分極時間を制御して、所定の分極度（長さモード素子の分極度ｄｆ＝５５ｋＨｚに対応した短冊の分極度）に調整した。その後、２５０℃×１ｈｒの条件でエージング処理を行った。

【００３５】ここでも、二次分極の範囲は、二次分極後の短冊の長さ振動モードの共振周波数と反共振周波数との差ｄｆを電気機械結合係数Ｋに換算した残留分極度Ｐr_2が、一次分極後のブロックの長さ振動モードの共振周波数と反共振周波数との差ＤＦを電気機械結合係数Ｋに換算した残留分極度Ｐr_1を越えない範囲としている。すなわち、

Ｐr_1 ≧Ｐr_2

二次分極後の短冊１Ａに対し、側面に露出した電極を１つおきに絶縁材で被覆し、その上に銀電極を形成した。これをダイサーで切断して、１．５mm×１．５mm×３．８mmの長さモード圧電共振子１Ｂを得た。この圧電共振子１Ｂの構造も第１実施例の圧電共振子と同じである。

【００３６】第３実施例における圧電共振子と、比較例における圧電共振子について、そのインピーダンスの周波数特性を測定し、共振周波数と反共振周波数との差としてｄｆ＝５５ｋＨｚの値を得た。表4は、第３実施例における分極度ｄｆおよび共振周波数ｆｒのロット変動を示す。表４から明らかなように、分極度ｄｆの標準偏差σ_{n-1} の平均値は１．０３ｋＨｚ、共振周波数ｆｒの標準偏差σ_{n-1} の平均値は０．９２ｋＨｚであり、分極度ｄｆのばらつきは第１実施例に比べてやや大きいが、共振周波数ｆｒのばらつきは3つの実施例の中で最も小さい。

【0037】

【表4】

－第３実施例－

評価工法（3ロット）

		評価ロット①	評価ロット②	評価ロット③	平均値
df	ave	54.72	54.91	55.91	55.18
	σ_{n-1}	0.96	0.99	1.14	1.03
	max	56.53	55.82	58.15	56.83
	min	51.61	50.44	52.50	51.52
	r	4.91	5.38	5.65	5.31

単位：KHz

		評価ロット①	評価ロット②	評価ロット③	平均値
fr	ave	450.62	449.56	452.26	450.81
	σ_{n-1}	0.71	0.93	1.12	0.92
	max	451.90	450.98	454.00	452.29
	min	447.93	446.20	448.68	447.60
	r	3.97	4.78	5.32	4.69

単位：KHz

【００３８】本発明の分極方法は、上記実施例に限定されるものではない。例えば、図１１～図１３では、短冊状の圧電体１Ａに対して１回だけ二次分極を行なったが、二次分極を複数回繰り返してもよい。つまり、電界方向を逆にして分極軸の反転を複数回繰り返してもよい。また、量産性および分極度分布を考慮して、ブロック状の積層圧電体に対して一次分極を行い、短冊状の積層圧電体に対して二次分極を行うようにしたが、ブロック状の積層圧電体に対して一次分極および二次分極を行ってもよいし、短冊状の積層圧電体に対して一次分極および二次分極を行ってもよい。

【００３９】なお、第１実施例および第２実施例（図５，６，１１，１２）において、二次分極後、分極軸が反転した圧電体層の残留分極度を仮にPr_2として説明した。これは理解しやすいようにモデル化したものであって、実際にはこれらの例では二次分極後の短冊全体（再分極層および分極軸が反転した圧電体層を含む）を長さ振動モードで励振させて、その残留分極度をPr_2とした。

【００４０】

【発明の効果】以上の説明で明らかなように、請求項１に記載の方法によれば、積層圧電体を厚み方向に一様に分極する一次分極を行った後、内部電極の片側の圧電体層の分極軸のみを反転させる二次分極を行う場合に、分極軸が反転した圧電体層における二次分極後の残留分極度Pr_2が一次分極後の残留分極度Pr_1を越えない範囲で二次分極を行うようにしたので、分極軸が反転した圧電体層の分極度分布が凸状あるいはフラットとなる範囲で二次分極を停止させることができる。そのため、分極軸が反転した圧電体層の分極度分布が凸状あるいはフラットで、分極軸が反転しない圧電体層の分極度分布が凹状であるから、積層圧電体全体としてみると、ほぼ均一な分極度分布が得られる。その結果、積層圧電体を切り出して使用するとき、その使用範囲が拡がり、収率が向上する。

【００４１】また、請求項２に記載の方法によれば、内部電極の両側の圧電体層を互いに逆向きに分極する一次分極を行った後、内部電極の両側の圧電体層の分極軸を反転させる二次分極を行う場合に、分極軸が反転した圧電体層における二次分極後の残留分極度Pr_2が一次分極後の残留分極度Pr_1を越えない範囲で二次分極を行うようにしたので、反転分極しない圧電体層が残らず、分極度分布を一層均一化できるとともに、隣合う圧電体層の分極度がほぼ等しいので、良好な共振特性を得ることができる。

【図面の簡単な説明】

【図１】本発明が対象とする圧電共振子の一例の斜視図である。

【図２】従来の積層圧電体の分極方法を示す図である。

【図３】図２の方法で分極されたブロック状圧電体の分極度分布を示す斜視図である。

【図４】初期分極時と分極反転時の分極度分布を示す図である。

【図５】請求項１にかかる分極方法の一例を示す工程図である。

【図６】図５に示す分極方法を行った時の隣合う二つの圧電体層の分極度分布の変化を示す図である。

【図７】請求項３にかかる分極方法の一例を示す工程図である。

【図８】図７に示す分極方法を行った時の隣合う二つの圧電体層の分極度分布の変化を示す図である。

【図９】二次分極の印加電圧を変化させたとき、分極反転層の分極度の変化を示す図である。

【図１０】図９のＡ～Ｆの各点における分極度分布図である。

【図１１】本発明の第１実施例における分極方法の一例を示す工程図である。

【図１２】本発明の第２実施例における分極方法の一例を示す工程図である。

【図１３】本発明の第３実施例における分極方法の一例を示す工程図である。

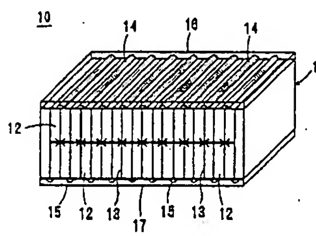
【符号の説明】

１　ブロック状積層圧電体

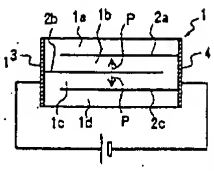
１Ａ　短冊状積層圧電体

１Ｂ	素子状積層圧電体	３，４	側面電極
１ａ〜１ｄ	圧電体層	５，６	表裏面電極
２ａ〜２ｃ	内部電極		

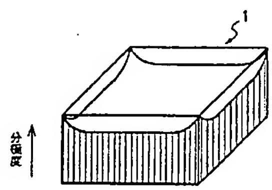
【図1】



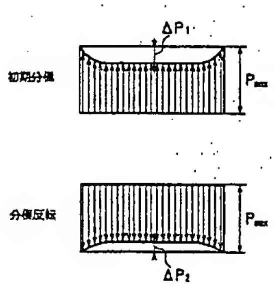
【図2】



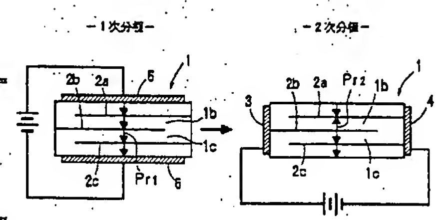
【図3】



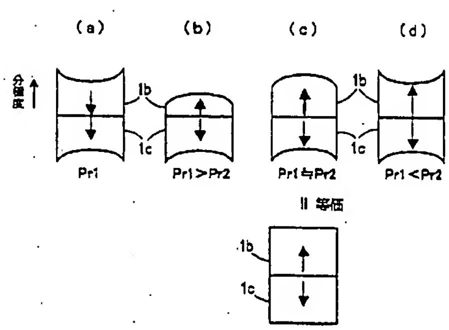
【図4】



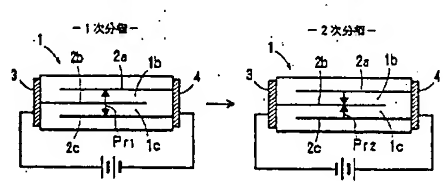
【図5】



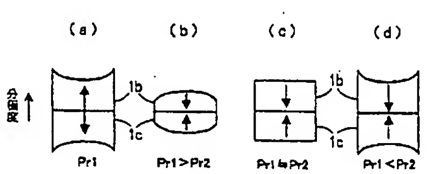
【図6】



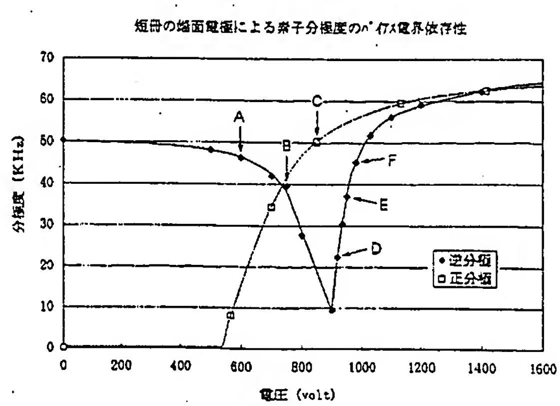
【図7】



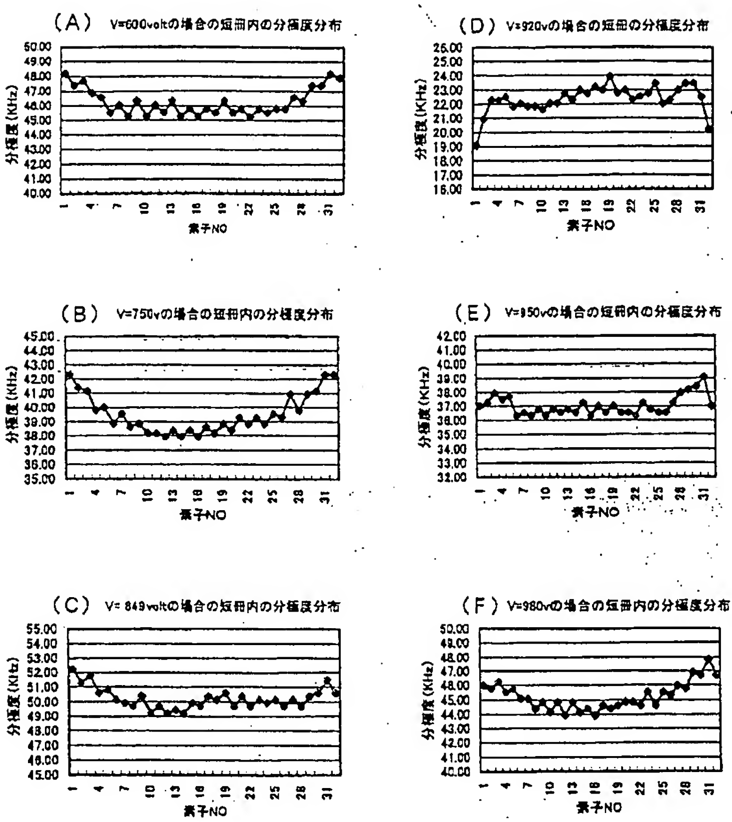
【図8】



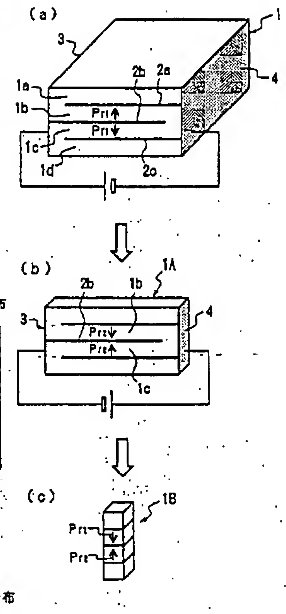
【図9】



【図10】


(A) V=600voltの場合の短冊内の分極度分布
(B) V=750vの場合の短冊内の分極度分布
(C) V= 849voltの場合の短冊内の分極度分布
(D) V=920vの場合の短冊の分極度分布
(E) V=950vの場合の短冊内の分極度分布
(F) V=980vの場合の短冊内の分極度分布
分極度(KHz)
素子NO

【図13】


(a)
(b)
(c)
1
3
4
1a
1b
1c
1d
2a
2b
Prt
1A
1B

(19) JAPANESE PATENT OFFICE (JP)

(12) Official Gazette for Unexamined Patent Applications (A)

(11) Japanese Unexamined Patent Application No. 2002-232032 (P2002-232032A)

(43) Disclosure date: 16 August 2002

(51) Int. Cl.[7]	FI	Subject code reference
H 0 1 L 41/22	H 0 1 L 41/22	B
		Z

Request for Examination: Not yet submitted

Number of claims: 4 OL

(Total of 11 pages [in the original])

(21) Patent Application No.: 2001-25160(P2001-25160)

(22) Filing date: 1 February 2001

(71) Applicant: 000006231
K.K. Murata Seisaku-jo
2-26-10 Tenjin, Nagaokakyo-shi, Kyoto-fu

(72) Inventor: NAKAJIMA Mikio
c/o K.K. Murata Seisaku-jo
2-26-10 Tenjin, Nagaokakyo-shi, Kyoto-fu

(74) Agent: 100085497
Patent attorney, TSUTSUI Hidenori

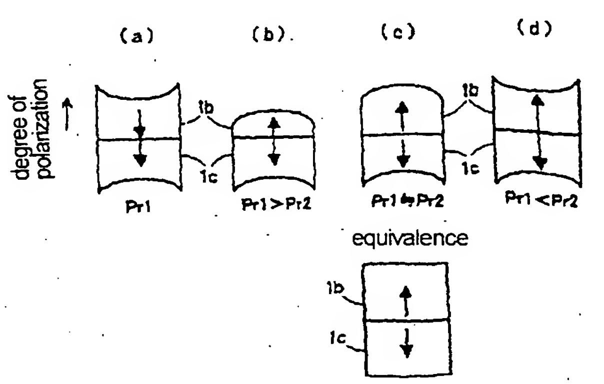
(54) [Title of the invention]

Method for polarizing stacked piezo-electric elements

(57) [Abstract]

[Object] To provide a method for polarizing a stacked piezo-electric element which makes the distribution of the degree of the polarization of the stacked piezo-electric element uniform and improves the yield.

[Solution] The method for polarizing the stacked piezo-electric element 1, in which a plurality of piezo-electric layers 1a to 1d and a plurality of internal electrodes 2a to 2c are alternately stacked and the adjacent piezo-electric layers 1b, 1c are polarized in opposite directions to one another in the thickness direction, comprises a primary polarization step in which a unidirectional electrical field is applied to the stacked piezo-electric element 1 in the thickness direction, and polarization is carried out uniformly in the thickness direction, and a secondary polarization step in which an opposite electrical field is applied to the piezo-electric layers 1b, 1c on both sides of the internal electrode 2b and only the polarization axis of the piezo-electric layer 1b of one side of the internal electrode 2b is inverted. The secondary polarization is carried out to such an extent that the degree Pr_2 of residual polarization after the secondary polarization in the piezo-electric layer 1b (in which the polarization axis is reversed) does not exceed the degree Pr_1 of residual polarization after the primary polarization.



[Scope of Patent Claims]

[Claim 1] Method for polarizing a piezo-electric element in which a plurality of piezo-electric layers and a plurality of internal electrodes are alternately stacked and the adjacent piezo-electric layers are polarized in opposite directions to one another in the thickness direction, characterized in that a primary polarization step is provided in which a unidirectional electrical field is applied to the abovementioned stacked piezo-electric element in the thickness direction, and polarization is carried out uniformly in the thickness direction, and a secondary polarization step in which respectively opposite electrical fields are applied to the piezo-electric layers on both sides of the abovementioned internal electrodes and only the polarization axis of the piezo-electric layer of one side of the internal electrode is inverted, and the abovementioned secondary polarization is carried out to such an extent that the degree Pr_2 of residual polarization after the secondary polarization in the piezo-electric layer in which the polarization axis has been reversed does not exceed the degree Pr_1 of residual polarization after the primary polarization.

[Claim 2] Method for polarizing a piezo-electric element according to Claim 1, characterized in that the abovementioned primary polarization step comprises a first step in which an electrical field of a first direction is applied to the abovementioned stacked piezo-electric element in the thickness direction, and a second step in which an electrical field of a direction opposite to that of the first direction is applied to the abovementioned stacked piezo-electric element in the thickness direction, and in that the polarization axes of the piezo-electric element formed in the first step are inverted uniformly by means of the abovementioned second step.

[Claim 3] Method for polarizing a piezo-electric

element in which a plurality of piezo-electric layers and a plurality of internal electrodes are alternately stacked and the adjacent piezo-electric layers are polarized in opposite directions to one another in the thickness direction, characterized in that a primary polarization step is provided in which respectively opposite electrical fields are applied to the piezo-electric layers on both sides of the abovementioned internal electrodes and the piezo-electric layers on both sides of the internal electrodes are polarized oppositely to one another, and a secondary polarization step is provided in which the electrical fields in the primary polarization step and electrical fields which are in the opposite direction are respectively oppositely applied to the piezo-electric layers on both sides of the abovementioned internal electrodes and the axis of polarization of the piezo-electric layers on both sides of the internal electrodes is inverted, and in that the abovementioned secondary polarization is carried out to such an extent that the degree Pr_2 of residual polarization after the secondary polarization in the piezo-electric layers in which the axis of polarization has been reversed does not exceed the degree Pr_1 of residual polarization after the primary polarization.

[Claim 4] Method for polarizing piezo-electric elements according to any one of Claims 1 to 3, characterized in that the abovementioned primary polarization is carried out on block-shaped stacked piezo-electric elements and the secondary polarization is carried out on block shaped stacked piezo-electric elements in the perpendicular direction with respect to the internal electrodes, on strip-shaped stacked piezo-electric elements cut into sections with a width of one component part.

[Detailed explanation of the invention]
[0001]

[Technical field of the invention] The present invention relates to a method for polarizing stacked piezo-electric elements which are used in mobile phone filters and the like, in particular to a method for polarizing stacked piezo-electric elements in which a plurality of piezo-electric layers and a plurality of internal electrodes are alternately stacked and adjacent piezo-electric layers are polarized in opposite directions to one another in the thickness direction.

[0002]

[Prior Art] In the prior art, a longitudinal-mode piezo-electric resonator element is provided which has a large degree of characteristic freedom of setting, small splices and large differences df between the resonant frequency and anti-resonant frequency (Japanese Laid-Open Patent Application H10-4330). Figure 1 shows an example of a longitudinal-mode piezo-electric resonator element 10. The piezo-electric resonator element 10 has a substrate 11 in which a plurality of piezo-electric layers 12 and a plurality of internal electrodes 13 are alternately stacked, and the piezo-electric layers 12 on both sides of the internal electrodes 13 are polarized oppositely to one another. Insulating films 14, 15 which cover every other internal electrode 13 are formed on the opposite face of the substrate 11, and furthermore external electrodes 16, 17 are formed on said insulating films 14, 15. For this reason, every other one of the external electrodes 16, 17 is alternately connected to the internal electrodes 13. As the polarization of the piezo-electric layer 12 has a particularly large influence when a piezo-electric resonator element 10 has such a configuration, there is a requirement to make the dispersion of the polarization within the elements or the dispersion of the polarization between the elements as small as possible.

[0003] This type of piezo-electric resonator element is manufactured by forming block-shaped stacked piezo-electric elements and subdividing them after they have been polarized. The polarization treatment of the stacked piezo-electric elements is carried out by means of the method shown in Figure 2. 1 is a stacked piezo-electric element composed of block-shaped piezo-electric ceramics, and here in order to give a simple explanation of this a configuration with four piezo-electric layers 1a to 1d is shown, but in fact a plurality of layers are stacked. Internal electrodes 2a to 2c are provided between the piezo-electric layers 1a to 1d, and the internal electrodes 2a to 2c are made to extend alternately into the exterior side face of the piezo-electric element 1 and are connected to the side-face electrodes 3, 4. Then, they are polarized in opposite directions to one another as shown by the arrow P with respect to piezo-electric layers 1b, 1c on both sides of the internal electrode 2b by applying a direct current electrical field between side-face electrodes 3, 4, and the specific degree of polarization is obtained.

[0004] However, with the method according to Figure 2 there is a problem that the distribution of degree of polarization is not uniform because the electrical fields are concentrated at the ends of the internal electrodes 2a to 2c. [illegible]? Figure 3 shows an example of the polarization distribution in one piezo-electric layer, the oblique ? line showing the degree of polarization. As is apparent from the figure, if the electrical field is applied to the piezo-electric element 1 in the thickness direction, the degree of polarization becomes appreciably higher at the four corners of the piezo-electric element 1 (concave-shaped distribution), and the uniform distribution of the degree of polarization is not obtained. As a result, if a configuration (block) in which such piezo-electric elements with a non-uniform distribution of the degree of polarization

are stacked is cut into a strip shape, and the strip is further cut and used as components, there is the problem that the piezo-electric elements at the periphery of the block cannot be used and the utilization rate (yield) of the piezo-electric elements is highly restricted.

[0005] For example, if piezo-electric elements for use in serial resonator elements (fr = 450 kHz, df = 55 kHz) which are used in radar-type filters are polarized with the method as in Figure 2, the dispersion of the degree of polarization within the block exhibits a large distribution of even as much as approximately 10 kHz. For this reason, as far as components which can be used as good quality items are concerned, good-quality components which can be used are only the components which are cut from near to the centre of the block and components from the periphery of the block mainly had poor polarization.

[0006] In this respect, the present applicants have proposed a method in which, after unidirectional polarization (initial polarization) has been carried out in the thickness direction of the stacked piezo-electric elements by applying an electrical field to the main face of the exterior electrodes facing the stacked piezo-electric element, side-face electrodes comprising internal electrodes which alternately extend out are formed and only the axes of polarization on the piezo-electric layers on one side of the internal electrodes are reversed (reversal of polarization) by applying an electrical field between the side-face electrodes, so that a specific degree of polarization is obtained (Japanese Laid-Open Patent Application 2000-52743). This method is based on the knowledge that even if, as shown in Figure 4, there is dispersion of the degree of polarization of ΔP_1 at the peripheral part and central part at the initial polarization stage, the distribution of the degree of polarization

can be reduced as far as ΔP_2, and the non-uniformity of the distribution of the degree of polarization of the initial stage polarization can be corrected, if an opposite electrical field is applied and the axis of polarization is inverted.

[0007]

[Problems to be solved by the invention] However, if the saturation degree of polarization Pmax of the piezo-electric layer in which the polarization axis has been reversed is polarized such that it becomes approximately equal to the saturation degree of polarization Pmax of the initial polarization stage, it can be said that the dispersion of the degree of polarization has been reduced, and the distribution of the degree of polarization of the piezo-electric layer whose polarization has been reversed becomes concave-shaped in the same way as before the reversal. For this reason, if, by means of the above method, there is a configuration in which the stacked piezo-electric elements have alternately stacked piezo-electric elements with opposite axes of polarization, piezo-electric layers which have polarization reversal and concave-shaped distribution and piezo-electric layers which do not have polarization reversal but do have concave-shaped distribution are stacked alternately and when the stacked piezo-electric elements are considered as a whole there is the possibility that a uniform distribution of the degree of polarization is not necessarily obtained.

why!

[0008] In this respect, the object of the present invention is to provide a method for polarizing stacked piezo-electric elements which makes as uniform as possible the distribution of the degree of polarization of the stacked piezo-electric elements considered as a whole and improves the yield.

[0009]

[Means of solving the problems] The abovementioned object is achieved by means of the invention according to Claim 1 of Claim 3. In other words, the invention according to Claim 1 provides a method for polarizing a piezo-electric element in which a plurality of piezo-electric layers and a plurality of internal electrodes are alternately stacked and the adjacent piezo-electric layers are polarized in opposite directions to one another in the thickness direction, which method comprises a primary polarization step in which a unidirectional electrical field is applied to the abovementioned stacked piezo-electric element in the thickness direction, and polarization is uniformly carried out in the thickness direction, and a secondary polarization step in which respectively opposite electrical fields are applied to the piezo-electric layers on both sides of the abovementioned internal electrodes and only the polarization axis of the piezo-electric layer of one side of the internal electrode is inverted, and the abovementioned secondary polarization is carried out to such an extent that the degree Pr_2 of residual polarization after the secondary polarization in the piezo-electric layer in which the polarization axis has been reversed does not exceed the degree Pr_1 of residual polarization after the primary polarization. In addition, the invention according to Claim 3 provides a method for polarizing a piezo-electric element in which a plurality of piezo-electric layers and a plurality of internal electrodes are alternately stacked and the adjacent piezo-electric layers are polarized in opposite directions to one another in the thickness direction, in which a primary polarization step is provided in which respectively opposite electrical fields are applied to the piezo-electric layers on both sides of the abovementioned internal electrodes and the piezo-electric layers on both sides of the internal electrodes are polarized oppositely to one another, and a secondary polarization step is provided in which the electrical fields in the

primary polarization step and electrical fields which are in the opposite direction are respectively oppositely applied to the piezo-electric layers on both sides of the abovementioned internal electrodes and axis of the polarization of the piezo-electric layers on both sides of the internal electrodes is inverted, and in that the abovementioned secondary polarization is carried out to such an extent that the degree Pr_2 of residual polarization after the secondary polarization in the piezo-electric layers in which the axis of polarization has been reversed does not exceed the degree Pr_1 of residual polarization after the primary polarization.

[0010] In Claim 1, a primary polarization is carried out during which a unidirectional electrical field is applied to the stepped piezo-electric element in the thickness direction, and polarization is carried out uniformly in the thickness direction. Then, secondary polarization is carried out during which an opposite electrical field is applied to the piezo-electric layers on both sides of the internal electrodes and only the axis of polarization of the piezo-electric layer on one side of the internal electrodes is reversed. Figure 5 shows an example of the polarization method relating to Claim 1. Firstly, front and rear electrodes 5, 6 are formed on the front and rear faces of the stacked piezo-electric element 1 and polarization (primary polarization) is carried out in one direction in the thickness direction, by applying a direct current electrical field to the stacked piezo-electric element 1 in the thickness direction. After this, the internal electrodes 2a, 2c are made to extend alternately from the outer side-faces of the stacked piezo-electric element 1 and are connected to the side-face electrodes 3, 4. Then, by applying a direct current electrical field between the side-face electrodes 3, 4, respectively opposite electrical fields are applied to the piezo-electric layers 1b, 1c

on both sides of the internal electrode 2b and only the axis of polarization of the piezo-electric layer 1b on one side of the internal electrode 2b is reversed (secondary polarization). It is to be noted that the piezo-electric layer 1c on the other side of the internal electrode 2b is merely re-polarized and the axis of polarization is not reversed.

[0011] The present inventors discovered, when carrying out various experiments by changing the polarization conditions at the time of secondary polarization, that the distribution of the degree of polarization of the piezo-electric layer 1b in which the axis of polarization has reversed is changed by means of the degree of progress of the secondary polarization (degree of residual polarization). Figure 6 is a schematic of an example of change in the distribution of the dregree of polarization of two piezo-electric layers 1b, 1c which accompanies the progress of the secondary polarization. The arrow shows the direction of polarization. (a) is the distribution of the degree of polarization after the primary polarization, at the same time it has concave-shaped distribution. (b) to (d) show the change in the distribution of the degree of polarization accompanying the progress of the secondary polarization. It is to be noted that Pr_1 shows the degree of residual polarization resulting from primary polarization, and Pr_2 shows the degree of residual polarization resulting from the secondary polarization. As is clear from Figure 6, the distribution of the degree of polarization of the piezo-electric layer 1b shows the convex-shaped or flat distribution as at the beginning (b), (c) of the reversal of the axis of polarization, but it changes to concave-shaped distribution as in (d) in due course. It is to be noted that the distributions of the degree of polarization of the piezo-electric layer 1b in (b) and (c) are convex-shaped examples but, depending on the materials, approximately flat distributions are also

seen. If secondary polarization progresses too far in this way, the distribution of the degree of polarization of the piezo-electric layer 1b becomes concave-shaped distribution (but with reversed direction of polarization) in the same way as at the time of primary polarization. It is to be noted that the distribution of the degree of polarization of the piezo-electric layer 1c which is repolarized continues to be concave-shaped as before. Therefore, in the state in which reverse polarization has progressed too far as in (d), the distribution of the degree of polarization of the piezo-electric layer 1b in which polarization has reversed and the distribution of the degree of polarization of the piezo-electric layer 1c in which the polarization has not reversed both become concave-shaped, and if the piezo-electric element is recorded as a whole the distribution of the degree of polarization does not become uniform.

[0012] In this respect, in Claim 1, the secondary polarization is stopped when it has reached an extent in which the distribution of the degree of polarization of the piezo-electric layer 1b in which the axis of polarization is reversed has become convex-shaped or flat. In other words, secondary polarization takes place to an extent that the degree Pr_2 of residual polarization after the secondary polarization does not exceed the degree Pr_1 of residual polarization after the primary polarization.

$Pr_1 \geq Pr_2$

In this way, the distribution of the degree of polarization of the piezo-electric layer 1b in which the axis of polarization has reversed is convex-shaped or flat and the distribution of the degree of polarization of the piezo-electric layer 1c in which the axis of polarization has not reversed is concave-shaped, so that the convex-shaped distribution of the degree of polarization and the concave-shaped distribution of the degree of polarization are, in

total, offset against one another, or the degree of non-uniformity of the concave-shaped distribution is reduced in relative terms, and if the stacked piezo-electric element 1 is considered as a whole, an approximately uniform distribution of the degree of polarization is obtained. As a result, the scope of use of the piezo-electric element becomes larger and the yield is improved. It is to be noted that if $Pr_1 > Pr_2$, the size of the degree of distribution of the two layers 1b and 1c becomes unbalanced but if the distribution of the degree of polarization is approximately uniform there is no adverse influence on the resonance characteristics as longitudinal oscillation mode elements. In particular, if $Pr_2 \fallingdotseq Pr_1$, the size of the degree of polarization of the two layers 1b and 1c becomes approximately equal, as shown in Figure 6 (c), becoming equal in value to the stacked piezo-electric element with uniform polarization and exhibiting extremely good characteristics.

[0013] In Claim 2, the primary polarization step is characterized in that it comprises a first process in which an electrical field of a first direction is applied in the thickness direction of the stacked piezo-electric element, and a second process in which an electrical field of a direction opposite to the first direction is applied in the thickness direction of the stacked piezo-electric element, and in that the axis of polarization of the stacked piezo-electric element which was formed in the first process is inverted uniformly by means of the second process. In other words the process in which primary polarization is carried out, or polarization is carried out uniformly on the stacked piezo-electric element in the thickness direction, may be carried out once only but, as in the initial polarization of Figure 4, the distribution of the degree of polarization becomes concave-shaped and the difference ΔP_1 between the centre part and the edge part is large. In this

respect, if the primary polarization is carried out a plurality of times and the axis of polarization is reversed over the whole of the stacked piezo-electric element, the difference ΔP_2 between the centre part and the edge part becomes small, in the same way as the polarization reversal in Figure 4, and the non-uniformity of the distribution of the degree of polarization in the primary polarization can be corrected. In this way, by correcting the non-uniformity of the distribution of the degree of polarization in the primary polarization, the non-uniformity of the distribution of the degree of polarization of the piezo-electric layers after the secondary polarization is also corrected. It is to be noted that the number of times in which the second process is carried out is not limited to one but rather may be carried out a plurality of times.

[0014] In Claim 3, first, opposite electrical fields are respectively applied to the piezo-electric layers on both sides of the internal electrodes, and primary polarization, in which the piezo-electric layers on both sides of the internal electrodes are oppositely polarized to one another, is carried out. After the primary polarization, the abovementioned electrical field and an electrical field in the opposite direction are respectively oppositely applied to the piezo-electric layers on both sides of the internal electrodes and secondary polarization in which the axis of polarization of the piezo-electric layers on both sides of the internal electrodes is reversed is carried out. In other words, the piezo-electric layers on both sides of the internal electrodes are reversed to the direction of the axis of polarization at the very beginning. Figure 7 shows an example of the polarization method relating to Claim 3. Firstly, internal electrodes 2a to 2c are made to extend alternately from the outer side faces of the stacked piezo-electric element 1 and side-face electrodes 3, 4

which are connected to these internal electrodes 2a to 2c are formed. Then, by applying a direct current electrical field between the side-face electrodes 3, 4, the piezo-electric layers 1b, 1c on both sides of the internal electrodes 2b are polarized oppositely to one another (primary polarization). This polarization step is the same as the polarization step according to the prior art (see Figure 2). Then, a direct current electrical field of the opposite direction is applied between the side-face electrodes 3, 4 and the axis of polarization of the piezo-electric layers 1b, 1c on both sides of the internal electrodes 2b is reversed at the same time (secondary polarization). In this case also, secondary polarization is carried out to the extent that the degree Pr_2 of residual polarization after the secondary polarization in the piezo-electric layers 1b, 1c in which the axis of polarization is reversed does not exceed the degree Pr_1 of residual polarization after the primary polarization. In this case, as the axes of polarization of the piezo-electric layers 1b, 1c on both sides of the internal electrodes 2b are reversed and the re-polarized layer is not present, the polarization conditions in the two layers 1b, 1c become the same, the distribution of the degree of polarization is made uniform and it is possible to make the size of the degree of polarization of the two layers 1b, 1c the same.

[0015] Figure 8 shows the change in the distribution of the degree of polarization in the piezo-electric layers 1b, 1c in the case in which secondary polarization has been carried out with the method shown in Figure 7. The arrow shows the direction of polarization. (a) is the distribution of the degree of polarization after primary polarization, it also has concave-shaped distribution. (b) to (d) show the change in the distribution of the degree of polarization accompanying the progress in the secondary polarization. After the axis of polarization has reversed as a result of the secondary polarization,

the degree of polarization of the two layers 1b, 1c is approximately the same, the distribution of the degree of polarization in said layers becomes flat or approximately convex-shaped and the degree of non-uniformity of the distribution of the degree of polarization of both layers 1b, 1c is reduced. Then, a secondary polarization is carried out until the degree Pr_2 of residual polarization and the degree Pr_1 of residual polarization resulting from the primary polarization approximately correspond, the two layers 1b, 1c both have, as shown in (c), flat or approximately convex-shaped distribution, and the degree of polarization becomes high, becoming an ideal distribution. If the secondary polarization is progressed further, the distribution becomes concave-shaped as in (d). Therefore, by setting the secondary polarization conditions in such a way that $Pr_1 \geq Pr_2$, it is possible to obtain the stacked piezo-electric element 1 which has a distribution of the degree of polarization which is uniform when considered as a whole.

[0016] As in Claim 4, it is desirable to carry out the primary polarization step on a block-shaped stacked piezo-electric element and the secondary polarization step on a strip-shaped stacked piezo-electric element. In other words, in order to increase the productivity, the primary polarization and secondary polarization may both be carried out on a block-shaped stacked piezo-electric element but since, as shown in Figure 3, the non-uniformity of the distribution of the degree of polarization at the time of the primary polarization appears in a three-dimensional form, the non-uniformity of the degree of polarization is difficult to eradicate if the secondary polarization is carried out on an unchanged block-shaped state. In this respect, if the secondary polarization is carried out after the piezo-electric element has been cut into strip shapes, it becomes possible to make the <u>dispersion</u> between the strips and within a strip small by virtue of the fact that the strength of the electrical field and timing

can be set in accordance with the distribution of the degree of polarization of the strips.

[0017] As, in the case of Claim 1, a stacked piezo-electric element on which primary polarization has been carried out is polarized uniformly in the thickness direction, lengthwise oscillations are not excited. In this respect, a difference DF between the resonant frequency of the lateral oscillation mode and the anti-resonant frequency is found and this is set as the degree of polarization. On the other hand, as the stacked piezo-electric element on which secondary polarization is carried out has the layer with an opposite direction of polarization, longitudinal oscillation is excited and the difference df between the resonant frequency of this longitudinal oscillation mode and the anti-resonant frequency is found and is set as the degree of polarization. As it is not possible to compare two types of degrees of polarization with different modes of oscillation in this way without modification, the lateral oscillation DF of the stacked piezo-electric element after the primary polarization is converted into a coefficient K of electromechanical coupling and set as the degree Pr_1 of residual polarization, while the df of the longitudinal oscillation of the stacked piezo-electric element after secondary polarization is converted into a coefficient K of electromechanical coupling and set as the degree Pr_2 of residual polarization, and by comparing these degrees, Pr_1, Pr_2, of residual polarization it is possible to determine the scope of secondary polarization. In addition, in the case of Claim 3, as there is a layer with an opposite direction of polarization as a result of the step carried out on the stacked piezo-electric element during which primary polarization was performed, longitudinal oscillation is excited. For this reason, it is possible to obtain both the degree Pr_1 of residual polarization of the primary polarization and the degree Pr_2 of residual

polarization of the secondary polarization from the values acquired by converting the difference df between the resonant frequency of the longitudinal oscillation and the anti-resonant frequency into a coefficient K of electromechanical coupling.

[0018]

[Embodiments of the invention] Figure 9 shows, for the specific PZT type of piezo-electric ceramic, the change in the degree Pr_2 of polarization of the layer in which the axis of polarization is reversed (referred to as the polarization reversal layer) in a strip at the time when the applied voltage of the secondary polarization is changed, when the degree Pr_1 of residual polarization of the primary polarization is set to 50 kHz, and Figure 10 shows the distribution of the degree of polarization at the points A to F in Figure 9. It is to be noted that, for reference, Figure 9 shows the change in the degree of polarization of the piezo-electric layers when the applied voltage is changed (referred to as normal polarization layers). The thickness of the polarization layer is set to 0.56 mm.

[0019] In Figure 9, as is apparent from Figure 10, in the polarization reversal layers the increase in the voltage of the secondary polarization is accompanied by depolarization, the axis of polarization is reversed at approximately 900 V, and after this the degree of polarization increases. After the polarization reversal, when the secondary polarization voltage approaches approximately 1000 V, the degree Pr_2 of residual polarization of the polarization reversal layer becomes approximately 50 kHz and the degree Pr_1 of residual polarization of the primary polarization becomes approximately equal. In the interval (see points D and E) up until the secondary polarization voltage approaches 900 V to approximately 1000 V, the distribution of the degree of polarization is almost flat or approximately convex-shaped and it is apparent

that when it reaches more than approximately 1000 V (see point F), the distribution of the degree of polarization becomes concave-shaped. Accordingly, the secondary polarization voltage in this case can be set such that $Pr_1 \geq Pr_2$, in other words within the range 900 V to 100 V.

[0020] It is to be noted that until 500 V is exceeded in the normal polarization layer, the degree of polarization remains at zero, but after this the degree of polarization increases. In the meantime, the distribution of the degree of polarization within the strip remains the same, i.e. concave-shaped, and does not change. Figures 9 and 10 do not show piezo-electric layers in which re-polarization has been carried out, but in the case of layers where re-polarization has occurred, the electrical field for the secondary polarization is not changed to the extent that the degree of polarization for the primary polarization is exceeded, and the degree of polarization of the secondary polarization does not become superior until the degree of polarization of the primary polarization is exceeded. In the meantime, the distribution of the degree of polarization inside the strip remains the same, i.e. the concave-shaped states, and does not change, in the same way as the layer with normal polarization.

[0021] An embodiment of the method for polarizing a stacked piezo-electric element according to the present invention and a comparative example will be explained below. In the embodiment example, a stacked piezo-electric element of the PZT type is used as the material for the longitudinal piezo-electric resonator element (df = 55 kHz).

[0022] (First embodiment) Figure 11 shows a manufacturing process for a longitudinal mode piezo-electric resonator element. Firstly, a conductive paste

for the internal electrodes, containing silver, palladium, organic binder and the like is applied to one side of green sheets composed of piezo-electric ceramics, and said sheets are stacked alternately, and a block-shaped piezo-electric element 1 with the dimensions 20 mm × 30 mm × 3.9 mm is formed by baking integrally at approximately 1200°C. Then, front and rear electrodes 5, 6 are formed on the front and rear faces of this block 1, direct current electrical fields are applied between the front and rear electrodes 5, 6 in a constant temperature vessel and primary polarization is carried out (see Figure 11 (a)). The conditions of the primary polarization are set such that the electrical field is 1.5 kV/mm, the polarization period is 10 min, and the maintained temperature is 70°C. After this, etching processing was carried out under the conditions of 150°C × 1 hr.

[0023] Then, side-face electrodes 3, 4 for extending the internal electrodes alternately outwards are formed on the side faces of the block-shaped stacked piezo-electric element 1 after the primary polarization. Using a dicer this piezo-electric element 1 is cut into strips with a width of one component in the vertical direction with respect to the internal electrodes 2a to 2c. A direct current electrical field is applied to the cut strips 1A by means of the side-face electrodes 3, 4 and secondary polarization is carried out (see Figure 11 (b)). At this time, the degree of polarization of individual strips 1A is set to a specific value by controlling the polarization time. The secondary polarization conditions are set such that the electrical field is 1.5 kV/mm and the polarization temperature is constant at 70°C. By controlling the polarization time, the polarization (the degree of polarization of the strip corresponding to the degree df = 55 kHz of longitudinal mode element polarization) is adjusted to a specific degree. After this, etching processing is carried out under the conditions of 250°C × 1 hr.

[0024] The range of the secondary polarization is set such that the value obtained by converting the difference df between the longitudinal oscillation mode resonant frequency and the anti-resonant frequency of the strip 1A after the secondary polarization to a coefficient of electromechanical coupling K (the degree Pr_2 of residual polarization) does not exceed the value obtained by converting the difference DF between the lateral oscillation mode resonant frequency and anti-resonant frequency of the block 1 after primary polarization (degree Pr_1 of residual polarization). In other words

$Pr_1 \geq Pr_2$

for the strip 1A after secondary polarization, and every other one of the electrodes which have been exposed on the side faces is covered with insulating material and a silver electrode is formed on top of these. This is cut using a dicer and a longitudinal mode piezo-electric resonator element 1B with the dimensions 1.5 mm × 1.5 mm × 3.8 mm is obtained (see Figure 11 (c)). Because the specific design of this piezo-electric resonator element 1B is the same as Figure 1 an explanation is omitted here.

[0025] (Comparative example) A block-shaped stacked piezo-electric element is formed using the same method as in the first embodiment example, side-face electrodes for alternately extending outwards the internal electrodes are formed in the side faces of said stacked piezo-electric element and a direct current electrical field is applied to the side-face electrodes of the stacked piezo-electric element in a constant temperature vessel and polarization is carried out (see Figure 2). The conditions for the polarization are set such that the electrical field is 1.5 kV/mm and the maintained temperature is constant at 70°C. By controlling the polarization time, the degree of polarization is adjusted to the specific degree of polarization DF = 2.0 ± 0.2 kHz. The degree DF of

polarization in this case is obtained from the difference between the lateral oscillation mode resonant frequency and anti-resonant frequency of the block. After this, etching processing is carried out under conditions of 250°C × 1 hr and a longitudinal mode piezo-electric resonator element is obtained by cutting to specific dimensions.

[0026] The frequency characteristics of the impedance of the two types of components obtained in the abovementioned way are set and the value df = 55 kHz is obtained as the difference between the resonant frequency and anti-resonant frequency. Tables 1 and 2 show comparisons of the batch fluctuations in the degree df of polarization and resonant frequency fr of the first embodiment example and comparative example in the special classification processes. δ_{n-1} is the standard deviation, and r is the difference between the maximum and minimum values.

[0027]
[Table 1]

①

②

		③ (1)	③ (2)	③ (3)	④
df	ave	56.15	55.82	55.03	55.67
	δ_{n-1}	0.90	0.92	0.90	0.91
	max	58.5	58.5	58.5	58.50
	min	54	53.5	52.5	53.33
	r	4.5	5	6	5.17

⑥

		③ (1)	③ (2)	③ (3)	④
fr	ave	450.8	449.72	449.86	450.13
	δ_{n-1}	0.90	1.03	1.10	1.01
	max	454	454	454.5	454.17
	min	448	447	447	447.33
	r	6	7	7.5	6.83

⑥

Key

① - First embodiment example -

② Evaluation method (three batches)

③ Evaluation batch

④ Average value

⑤ Batch

⑥ Unit: kHz

⑦ Comparative example

⑧ Evaluation method (five batches)

[0028] [Table 2]

⑦

⑧

		⑤ (1)	⑤ (2)	⑤ (3)	⑤ (4)	⑤ (5)	④
df	ave	56.44	56.22	56.41	56.69	56.31	56.41
	δ_{n-1}	2.16	1.97	2.09	2.01	1.97	2.04
	max	63.00	62.50	62.50	63.00	63.00	62.80
	min	52.50	51.50	52.50	53.00	53.00	52.50
	r	10.50	11.00	10.00	10.00	10.00	10.30

⑥

		⑤ (1)	⑤ (2)	⑤ (3)	⑤ (4)	⑤ (5)	④
fr	ave	448.99	448.69	448.63	448.96	447.88	448.63
	δ_{n-1}	1.37	1.41	1.19	1.29	1.15	1.28
	max	452.50	452.00	451.50	452.00	450.50	451.70
	min	444.50	443.50	444.50	445.00	444.50	444.40
	r	8.00	8.50	7.00	7.00	6.00	7.30

⑥

[0029] As is clear from Tables 1 and 2, if comparisons are made using the average values of the standard deviation δ_{n-1} of df, in the first embodiment example said average value is 0.91 kHz and in the case of the comparative example it is 2.04 kHz, and compared with the comparative example with the first embodiment example it was possible to improve the dispersion of the degree df of polarization by approximately 1/2. In addition, if comparisons are made using the average values of the standard deviation δ_{n-1} of the resonant

frequency fr, in the first embodiment example said average value was 1.01 kHz and in the comparative example it was 1.28 kHz, and it was possible to improve the dispersion of the resonant frequency fr by approximately 30%.

[0030] (Second embodiment example) Figure 2 shows a manufacturing process for a second embodiment example of the longitudinal mode oscillation resonator element. In this embodiment example, the primary polarization was carried out a plurality of times at the stage of the block 1 (see Figure 12(a) and 12(b)), and the axis of polarization was reversed over the whole of the block 1. In this case, the difference ΔP_2 between the centre part and the edge part becomes small, in the same way as in the polarization reversal in Figure 4, and at the stage in which the piezo-electric element is cut into strips 1A in (c), the dispersion of the degree of polarization (concave-shaped distribution) between the strips 1A and inside the strips 1A becomes small. For this reason, if secondary polarization is carried out in (c), the concave-shaped distribution of the degree of polarization of the piezo-electric layer 1c which has been re-polarized after secondary polarization is made uniform. It is to be noted that the number of processes in (b) is not limited to one, and said process may be executed a plurality of times..

[0031] Table 1 shows the batch deviation of the degree df of polarization and resonant frequency fr in the second embodiment example. As is apparent from Table 3, the average value of the standard deviation δ_{n-1} of the degree df of polarization is 0.85 kHz, and the average value of the standard deviation δ_{n-1} of the resonant frequency fr is 0.96 kHz, so that it was possible to achieve a further improvement in the dispersion in comparison with the first embodiment example.

[0032]

[Table 3]

①

②

		④ (1)	④ (2)	④ (3)	③
df	ave	53.93	53.44	54.03	53.80
	δ_{n-1}	0.96	0.71	0.87	0.85
	max	58.00	55.00	57.50	56.83
	min	50.00	51.50	52.00	51.17
	r	8.00	3.50	5.50	5.67

⑤

		④ (1)	④ (2)	④ (3)	③
fr	ave	449.15	448.93	449.06	449.05
	δ_{n-1}	0.85	0.97	1.06	0.96
	max	451.50	452.00	451.50	451.67
	min	446.00	446.00	446.00	446.17
	r	5.50	6.00	5.00	5.50

⑤

Key to table

① - Second embodiment example -

② Evaluation method (three batches)

③ Average value

④ Evaluation batch

⑤ Unit: kHz

[0033] (Third embodiment example) Figure 13 shows the manufacturing process for the longitudinal mode piezo-electric resonator element according to the third embodiment example. A conductive paste for the internal electrodes, containing silver, palladium, organic binder and the like is applied to one side of green sheets composed of piezo-electric ceramics, and said sheets are stacked alternately, and a block-shaped piezo-electric element 1 with the dimensions 20 mm × 30 mm × 3.9 mm is formed by baking integrally at approximately 1200°C. Then, side-face electrodes 3, 4 for alternately extending the internal electrodes are formed in the side faces of the stacked piezo-electric

element 1 and a direct current electrical field is applied between the side-face electrodes in a constant temperature vessel and primary polarization is carried out (see 13(a)). The conditions for the primary polarization are such that the electrical field is 1.5 kV/mm, the polarization time is 10 min and the maintained temperature is 70°C. After this, etching processing is carried out under conditions of 150°C × 1 hr.

[0034] Then, using a dicer, the etched block-shaped stacked piezo-electric element 1 is cut up into strip shapes with a width of one component in the vertical direction with respect to the internal electrodes. A direct current electrical field is applied to the cut-out strips 1A by means of the side-face electrodes 3, 4 and secondary polarization is carried out (see Figure 13(b)). At this time, the direction of the application of voltage to the strips 1A is made the opposite of that with the primary polarization. By controlling the polarization time, the degree of polarization of the individual strips 1A was set to specific values. The conditions for the secondary polarization are such that the electrical field is 1.5 kV/mm, and the polarization temperature is 70°C. By controlling the polarization time, the polarization is adjusted to a specific degree (degree of polarization of the strip corresponding to degree of polarization of the longitudinal mode element df = 55 kHz). After this, etching processing is carried out under conditions of 250°C × 1 hr.

[0035] The range of the secondary polarization was set such that the value obtained by converting the difference df between the longitudinal oscillation mode resonant frequency and the anti-resonant frequency of the strip after the secondary polarization to a coefficient K of electromechanical coupling (the degree Pr_2 of residual polarization) did not exceed the value

obtained by converting the difference DF between the lateral oscillation mode resonant frequency and anti-resonant frequency of the block 1 after primary polarization (degree Pr_1 of residual polarization). In other words

$Pr_1 \geq Pr_2$

for the strip 1A after secondary polarization, and every other one of the electrodes which have been exposed on the side faces is covered with insulating material and a silver electrode is formed on top of these. This is cut using a dicer and a longitudinal mode piezo-electric resonator element 1B with the dimensions 1.5 mm × 1.5 mm × 3.8 mm is obtained. The structure of this piezo-electric resonator element 1B is the same as piezo-electric resonator element according to the first embodiment example.

[0036] The frequency characteristics of the impedance of the piezo-electric resonator element in the third embodiment example and the piezo-electric resonator element in the comparative example are measured and a value df = 55 kHz is obtained as the difference between the resonant frequency and anti-resonant frequency. Table 4 shows batch deviations for the degree df of polarization and resonant frequency fr in the third embodiment example. As is apparent from Table 4, the average value of the standard deviation δ_{n-1} of the degree df of polarization is 1.03 kHz and the average value of the standard deviation δ_{n-1} of the resonant frequency fr is 0.92 kHz so that, compared to the first embodiment example, the dispersion of the degree df of polarization is slightly larger but the dispersion of the resonant frequency fr is very much smaller in the third embodiment example.

[0037]

[Table 4]

①

②

		④ (1)	④ (2)	④ (3)	③
df	ave	54.72	54.91	55.91	55.18
	δ_{n-1}	0.96	0.99	1.14	1.03
	max	56.53	55.82	58.15	56.83
	min	51.61	50.44	52.50	51.52
	r	4.91	5.38	5.65	5.31

⑤

		④ (1)	④ (2)	④ (3)	③
fr	ave	450.62	449.56	452.26	450.81
	δ_{n-1}	0.71	0.93	1.12	0.92
	max	451.90	450.98	454.00	452.29
	min	447.93	446.20	448.68	447.60
	r	3.97	4.78	5.32	4.69

⑤

Key to Table 4

① - Third embodiment example -
② Evaluation method (3)
③ Average value
④ Evaluation batch
⑤ Unit kHz

[0038] The polarization method according to the present example is not limited to the abovementioned embodiment examples. For example in Figures 11 to 13, secondary polarization was carried out only once on the strip-shaped piezo-electric element 1A but secondary polarization may also be repeated a plurality of times. In other words, the reversal of the axis of polarization by reversing the direction of the electrical field may be repeated a plurality of times. In addition, considering mass production and distribution of the degree of polarization, primary

polarization was carried out on the block-shaped stacked piezo-electric element and secondary polarization was carried out on the strip-shaped stacked piezo-electric element, but it is also possible to carry out primary polarization and secondary polarization on a block-shaped stacked piezo-electric element, and it is also possible to carry out primary polarization and secondary polarization on a strip-shaped stacked piezo-electric element.

[0039] It is to be noted that in the first embodiment example and second embodiment example (Figures 5, 6, 11, 12), the degree of residual polarization of the piezo-electric layers in which the axis of polarization has been reversed is provisionally set to Pr_2 and an explanation given. In order to make this easy to understand, it has been presented in a schematic form, and in fact in these examples the entirety of the strip after secondary polarization (including the layers with repolarization and the piezo-electric layers in which the axis of polarization has been reversed) have been excited in longitudinal oscillation mode and their degree of residual polarization has been set to Pr_2.

[0040]

[Effects of the invention]

It is apparent from the above explanation, in the method according to Claim 2, if secondary polarization which reverses only the axis of polarization of the piezo-electric layer on one side of the internal electrodes is carried out after primary polarization which polarizes the stacked piezo-electric element uniformly in the thickness direction has been performed, secondary polarization is carried out to such an extent that the degree Pr_2 of residual polarization after the secondary polarization in the piezo-electric piezo-electric layers in which the axis of polarization has been reversed does not exceed the degree Pr_1 of residual polarization after the primary

polarization so that it is possible to stop the secondary polarization at the extent in which the distribution of the degree of polarization of the piezo-electric layers in which the axis of polarization has been reversed has become convex-shaped or flat. For this reason, the distribution of the degree of polarization in the piezo-electric layers in which the axis of polarization has been reversed is convex-shaped or flat and the distribution of the degree of polarization in the piezo-electric layers in which the axis of rotation has not been reversed is concave-shaped with the result that, if the stacked piezo-electric element is considered as a whole, an almost uniform distribution of the degree of polarization is obtained. As a result, when the stacked piezo-electric element is cut out and used, its scope of use is made larger and the yield is improved.

[0041] In addition, in the method according to Claim 2, if secondary polarization in which the axes of polarization of the piezo-electric layers on both sides of the internal electrodes are reversed after primary polarization in which the piezo-electric layers on both sides of the internal electrodes are polarized oppositely to one another is carried out, secondary polarization is carried out to such an extent that the degree Pr_2 of residual polarization after the secondary polarization in the piezo-electric layers in which the axis of rotation has been reversed does not exceed the degree Pr_1 of residual polarization after the primary polarization so that there are no longer any piezo-electric layers without reversal of the polarization and it is possible to make the distribution of the degree of polarization more uniform and make the degree of polarization of adjacent piezo-electric layers almost equal so that satisfactory resonance characteristics can be obtained.

[Brief description of the figures]

Figure 1 is an oblique view of an example of a piezo-electric resonator element according to the present invention.

Figure 2 shows a method of polarizing a stacked piezo-electric element according to the prior art.

Figure 3 is an oblique view showing the distribution of the degree of polarization of a block-shaped piezo-electric element which has been polarized using the method in Figure 2.

Figure 4 shows the distribution of the degree of polarization at the beginning of polarization and at the time when the polarization is reversed.

Figure 5 is a process diagram showing an example of the polarization method relating to Claim 1.

Figure 6 shows the change in the distribution in the degree of polarization in two adjacent piezo-electric layers at the time when the polarization method shown in Figure 5 has been carried out.

Figure 7 is a process diagram showing an example of the polarization method relating to Claim 3.

Figure 8 shows the change in the distribution of the degree of polarization in two adjacent piezo-electric layers at the time when the polarization method shown in Figure 7 has been carried out.

Figure 9 shows the change in the degree of polarization in a layer with a reversal of the polarization at the time when the applied voltage for secondary polarization has been changed.

Figure 10 is a figure showing the distribution of the

degree of polarization at the points A to F in Figure 9.

Figure 11 is a process diagram showing an example of the polarization method in the first embodiment example according to the present invention.

Figure 12 is a process diagram showing an example of the polarization method in the second embodiment example according to the present invention.

Figure 13 is a process diagram showing an example of the polarization method in the third embodiment example according to the present invention.

[Key to symbols]

1	Block-shaped stacked piezo-electric element
1A	Strip-shaped stacked piezo-electric element
1B	Component-shaped stacked piezo-electric element
1a to 1d	Piezo-electric layers
2a to 2c	Internal electrodes
3, 4	Side-face electrodes
5, 6	Front and rear electrodes

Figure 1

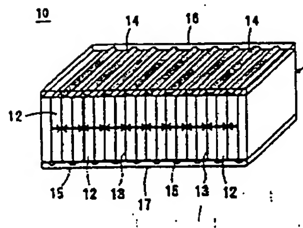


Figure 2

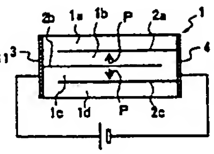


Figure 3

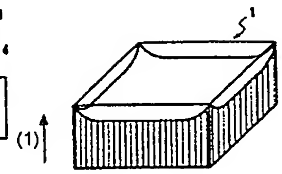


Figure 4

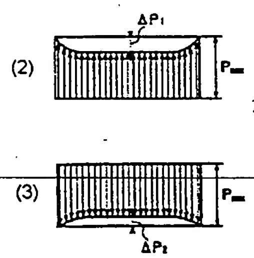


Figure 5

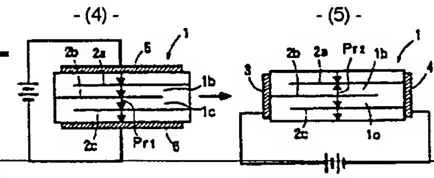


Figure 7

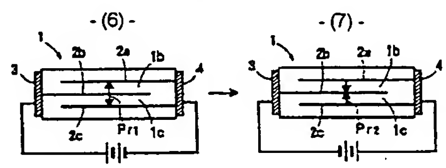


Figure 6

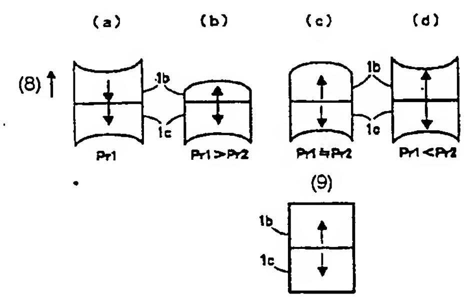


Figure 9

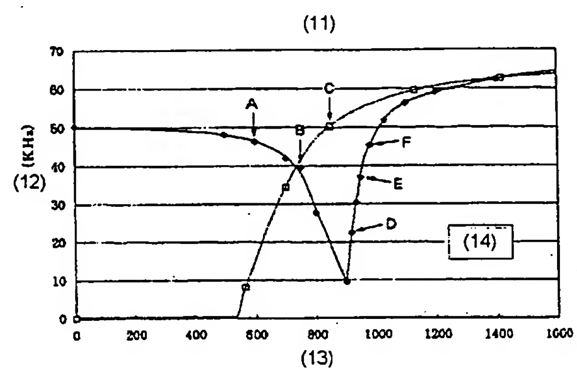


Figure 8

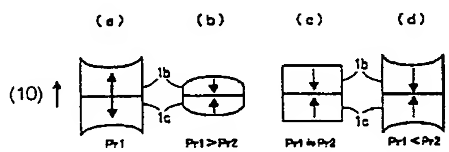


Figure 11

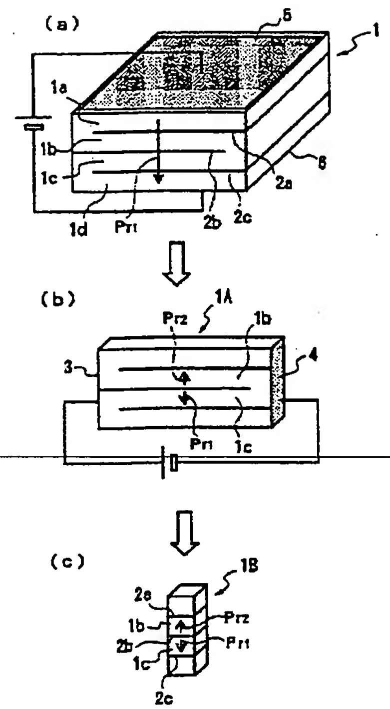


Figure 12

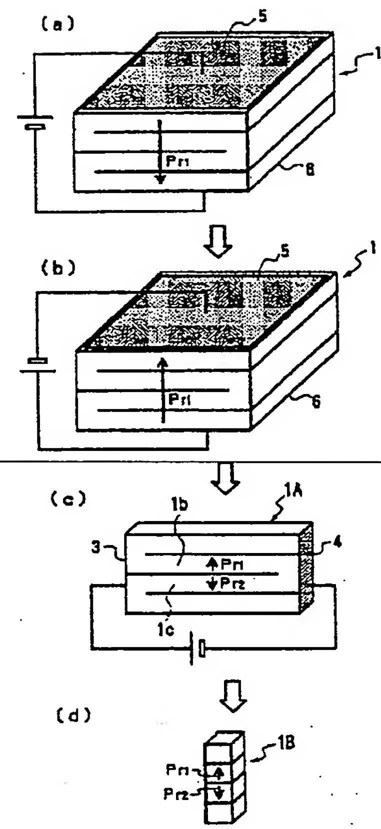


Figure 10

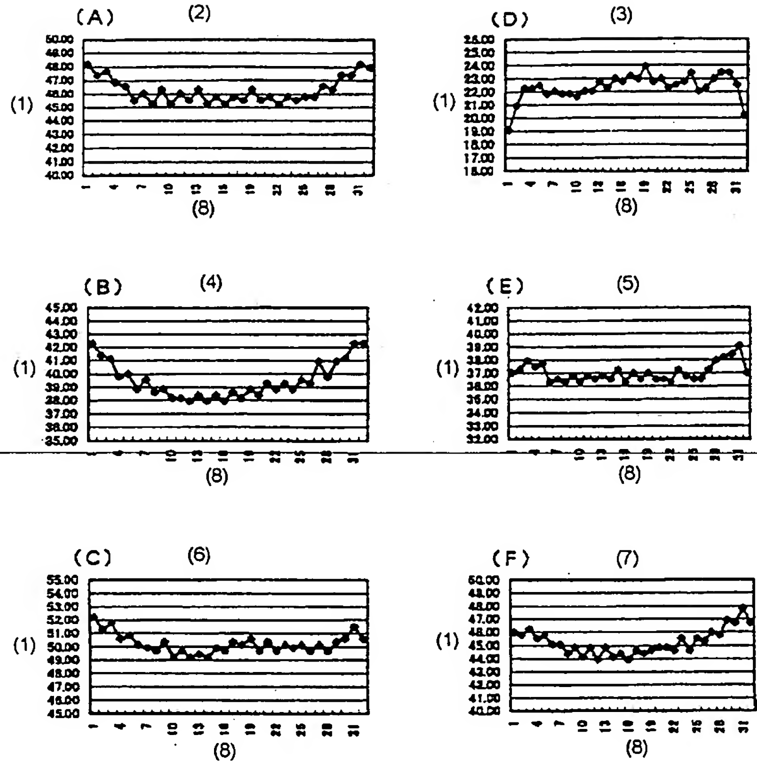
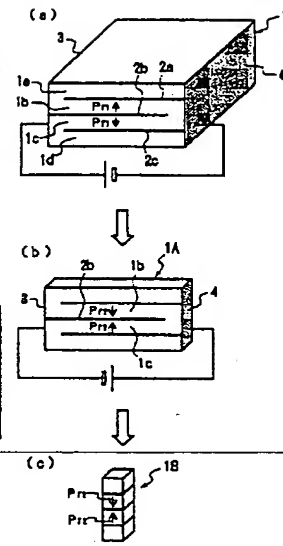


Figure 13



Key to Figures 10 and 13

1 Degree of polarization (kHz)
2 Distribution of degree of polarization inside strip with V = 600 volts
3 Distribution of degree of polarization inside strip with V = 920 V
4 Distribution of degree of polarization inside strip with V = 750 V
5 Distribution of degree of polarization inside strip with V = 950 V
6 Distribution of degree of polarization inside strip with V = 849 volts
7 Distribution of degree of polarization inside strip with V = 980 V
8 Component no.

Key to Figures 1 - 9

1	Degree of polarization
2	Initial polarization
3	Reversal of polarization
4	primary polarization
5	secondary polarization
6	primary polarization
7	secondary polarization
8	Degree of polarization
9	Equivalence
10	Degree of polarization
11	Dependence of biasing electrical field on degree of component polarization in edge-face electrodes of strip
12	Degree of polarization
13	Volts
14	Reverse polarization
	Normal polarization

P.7 - "concave distribution of "degree of polarisation", leading to higher component wastage as corners cannot be used.
+periphery

- we cut ours into elements first and then apply two-stage poling process

polarisation of layers has an effect on the resonant frequency of the element.
aim to make the "dispersion" of polarisation within elements or between elements as small as possible.

df - difference between resonant and anti-resonant frequency.

ie: fr (resonant frequency) = 450kHz df . 55kHz df is effectively a resonant band

---

aim · primary polarisation - poling whole stock
· secondary polarisation - electric field produced between both sets of internal electrodes

Novel feature - primary poling and secondary poling occurs on a ferroelectric stack
a plurality of stacks

conventionally, a stack is formed from a single monolithic block of ferroelectric material.